

EFFECTS OF GROUND EQUALIZATION ON THE ELECTRICAL PERFORMANCE OF ASYMMETRIC CPW SHUNT STUBS

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ABSTRACT

A hybrid technique is used to study the effects of ground equalization on the electrical performance of CPW shunt stubs. Extensive experiments have been performed and the results are in good agreement with theoretical data. The advantages of using air-bridges in CPW circuits as opposed to bond-wires are also discussed.

1 INTRODUCTION

In state-of-the-art MMIC's, coplanar waveguide (CPW) is becoming widely used due to several advantages it offers over the conventional microstrip line. However, air-bridges are unavoidable especially when CPW circuits are combined with other planar lines and when asymmetries in the structure give rise to the radiating slotline mode. Recently, transversely symmetric CPW discontinuities with air-bridges (or bond-wires) have been numerically studied and the results of these studies can be found in [1]-[5]. On the other hand, some results for asymmetric CPW discontinuities with air-bridges have been presented in the literature [6]-[8]. In this paper, an extensive theoretical and experimental study of the short-end asymmetric CPW shunt stub (shown in Figure 1(a)), with emphasis on the effectiveness of ground equalization, is presented. The details of the theoretical approach can be found in [8], and thus, they will not be included here. Extensive experiments on asymmetric CPW shunt stubs have been performed and the fabrication and measurement procedures are described in section 2. Two different approaches have been used to obtain ground equalization in CPW shunt stub circuits. In one approach, equalization is achieved using bond-wires, while, in the other approach bond-wires are substituted by air-bridges. It is shown that air-bridges give circuits with better electrical performance than bond-wires.

2 FABRICATION AND MEASUREMENTS

Two different approaches are used to obtain ground equalization in the shunt stub circuits shown in Figure 1. In the first approach, equalization is achieved using bond-wires,

while, in the second the ground planes are connected with air-bridges.

2.1 Circuits with Bond-Wires

A 300 Å seed layer of Cr and a 600 Å layer of Au is evaporated on a 3 inch high-resistivity silicon wafer. This metalization provides the electrical contact for the electroplating. A photolithographic process is then used to define the various shunt stub geometries and the plating contact area. Approximately 3 μm of gold is electroplated to achieve the required number of skin depths, then, bond-wires are added to the circuits using a Marpet Enterprises wire bonder and 0.7 mil thick gold thread.

2.2 Circuits with Air-Bridges

In this case, the circuits are fabricated on a 483 μm thick GaAs substrate using a lift-off processing technique. The CPW center strip and ground planes consist of 200 Å of Cr and 1.5 μm of Au. The air-bridges have 15 μm square posts and a height and width of 3.5 μm and 15 μm, respectively. The bridge itself is 1.5 μm thick and was fabricated by lift-off.

2.3 Measurements

All of the circuits are measured with a probe station and Cascade Microtech high frequency CPW probes attached to an HP 8510B Network Analyzer. To suppress parallel plate and microstrip modes between the CPW circuits and the wafer chuck of the probe station during testing, the wafer is placed on a piece of 0.125 inch thick 5880 RT/Duroid. A Thru-Reflect-Line (TRL) calibration is performed to eliminate the effects of the connectors, cables, and probes from the measured data and to accurately place the system reference planes at the reference planes of the stubs. The calibration standards required for the TRL include a thru, an open, and several delay lines. Three delay lines are used in the calibration of the circuits with air-bridges to cover the full 5-40 GHz bandwidth, whereas only one delay line is used in the case of the circuits with bond-wires to cover 10-30 GHz bandwidth. After calibrating, S-parameter measurements of the circuits are used to compare the theoretical and experimental results.

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3 RESULTS AND DISCUSSION

In the theoretical analysis, the considered CPW discontinuities are suspended inside a rectangular cavity as shown in Figure 2. Two examples are presented in this section. In the first example, experimental results obtained from the circuits with bond-wires are compared to theoretical data. In the second example, experimental results for the circuits with air-bridges are compared to theoretical data and the radiation loss from the stubs is experimentally investigated.

3.1 Example 1: Stubs with Bond-Wires

A comparison between theoretical and experimental results for an asymmetric stub discontinuity without longitudinal bond-wire (with the transverse bond-wires present) is shown in Figure 3. For this structure, $h=353\text{ }\mu\text{m}$, $\epsilon_{r1}=11.7$, $\epsilon_{r2}=1$, $S=140\text{ }\mu\text{m}$, $W=100\text{ }\mu\text{m}$, $a=4.56\text{ mm}$, $D_1=3.5\text{ mm}$ and $D_2=1.8\text{ mm}$. In addition, the CPW stub has a slot width of $100\text{ }\mu\text{m}$ and a center conductor of $140\text{ }\mu\text{m}$. The measurements were done on unshielded structures and transverse bond-wires were used to connect the ground planes as it was discussed in the previous section. In Figure 3, the discrepancy between theory and experiment is due to the fact that bond-wires are not very effective in suppressing the slotline mode, thus resulting in high radiation loss from the measured stub. It should be mentioned here that in the fabricated circuits, the transverse bond-wires, which connect the ground planes of the feeding lines, were placed at a distance of $90\text{ }\mu\text{m}$ from the junction. However, the theoretical methodology assumes that ideal transverse air-bridges exist exactly at the junction [8].

Figure 4 shows the scattering parameters (theoretical and experimental) of the same asymmetric stub after including the longitudinal bond-wire in the experiments and taking a longitudinal air-bridge into consideration in the theory. The air-bridge is assumed to be of height $3\text{ }\mu\text{m}$ and width of $10\text{ }\mu\text{m}$. In this figure, the agreement between theory and experiment is better than that in Figure 3. This is due to the fact that the longitudinal bond-wire tends to suppress the radiating slotline mode in the measured stub. The difference in the resonant frequency can be attributed to the fact that the longitudinal bond-wire, which connects the stub ground planes, was placed at a distance of $190\text{ }\mu\text{m}$ from the junction. This reduces the effective length of the stub, and thus, increases the measured resonant frequency. On the other hand, the derived theoretical data for this discontinuity are based on the assumption that a longitudinal air-bridge is placed exactly at the junction. Another reason for the discrepancy in the resonant frequency is the relatively thick metallization used in the circuits with bond-wires ($3\text{ }\mu\text{m}$) which is neglected in the theoretical analysis. The finite metallization thickness reduces the phase constant [9], and thus, increases the stub resonant frequency.

3.2 Example 2: Stubs with Air-Bridges

Figures 5 and 6 show the scattering parameters (theoretical and experimental) of an asymmetric stub with and without the longitudinal air-bridge (with the presence of the transverse air-bridges). For this structure, $h=483\text{ }\mu\text{m}$, $\epsilon_{r1}=13$, $\epsilon_{r2}=1$, $S=32\text{ }\mu\text{m}$, $W=20\text{ }\mu\text{m}$, $a=4.318\text{ mm}$, $D_1=3.0\text{ mm}$ and $D_2=3.175\text{ mm}$. In addition, the CPW stub has a slot width of $15\text{ }\mu\text{m}$ and a center conductor of $20\text{ }\mu\text{m}$. The measurements were performed on unshielded structures and air-bridges were used to connect the ground planes. As opposed to bond-wires, the air-bridges were placed at the junction. The agreement between theory and experiment is very good which validates both sets of data. The discrepancy seen around the second resonance is mainly due to radiation losses. It is interesting to note that the electric performance of the stub is not affected by the presence of the longitudinal air-bridge. The resonant frequencies shown in Figures 5 and 6 differ by almost 0.8 GHz only. The reason is that the dimensions of the stub (slot and center conductor widths) are very small, and thus, the transverse air-bridges tend to equalize the potential of the two ground planes of the stub as well as the ground planes of the feeding lines. A symmetric CPW stub (shown in Figure 1(b)) with the same dimensions has also been measured and found to have a higher Q-factor and a somewhat higher resonant frequency than the asymmetric stub [8].

Figure 7 shows the measured loss factor for both the symmetric and asymmetric CPW shunt stubs with all air-bridges present. It can be seen that the higher Q which has been observed for the symmetric case is not due to lower losses but rather due to more energy stored around the symmetric stub than that stored in the asymmetric one. It can be also observed that the loss factor for the symmetric stub increases with frequency at nearly linear rate whereas the loss factor for the asymmetric stub decreases to a minimum at the first resonant frequency and then passes to a maximum at the second resonant frequency where the stub is half a wavelength long. This increase in the loss factor at the second resonance is due to the radiation loss attributed to the slotline mode. It seems that the slotline mode is not excited as strongly in the symmetric stub and, thus, there is no corresponding increase in radiation loss at the second resonance. The decrease in the loss factor for the asymmetric stub at the first resonance has been confirmed by repeated measurements.

4 CONCLUSIONS

A general theoretical approach has been applied to the asymmetric short-end CPW shunt stub. Extensive experiments have been performed on CPW circuits with bond-wires and air-bridges. The circuits with bond-wires are much easier to fabricate but some of the accuracy is sacrificed. Air-bridges provide much more accuracy in the measurements, though they are more difficult to fabricate. It has been found that the asymmetric stub has a lower Q than the symmetric stub with the same dimensions. In addition, it has been demonstrated that a longitudinal air-bridge is not needed in an asymmetric CPW shunt-stub if the dimensions of the stub are very small.

5 ACKNOWLEDGMENT

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References

- [1] M. Rittweger, M. Abdo and I. Wolff, "Full-Wave Analysis of Coplanar Discontinuities Considering Three-Dimensional Bond Wires," *1991 IEEE MTT-S International Microwave Symposium Digest*, pp. 465-468.
- [2] K. Beilenhoff, W. Heinrich and H. Hartnagel, "The Scattering behavior of Air Bridges in Coplanar MMIC's," *Proc. of 21st Eu. M. C.*, pp. 1131-1135, Sep. 1991.
- [3] H. Jin and R. Vahldieck, "Calculation of Frequency-Dependent S-Parameters of CPW Air-Bridges Considering Finite Metallization Thickness and Conductivity," *1992 IEEE MTT-S International Microwave Symposium Digest*, pp. 207-210.
- [4] N. Dib, L. P. Katehi and G. Ponchak, "Analysis of Shielded CPW Discontinuities with Air Bridges," *1991 IEEE MTT-S International Microwave Symposium Digest*, pp. 469-472.
- [5] N. Dib, G. Ponchak and L. P. Katehi, "A Comprehensive Theoretical and Experimental Study of CPW Shunt Stubs," *1992 IEEE MTT-S International Microwave Symposium Digest*, pp. 947-950.
- [6] M. Rittweger, *et al.*, "Full-Wave Analysis of a Modified Coplanar Air Bridge T-Junction," *Proc. of 21st Eu. M. C.*, pp. 993-998, Sep. 1991.
- [7] R. Bromme and R. Jansen, "Systematic Investigation of Coplanar Waveguide MIC/MMIC Structures Using a Unified Strip/Slot 3D Electromagnetic Simulator," *1991 IEEE MTT-S International Microwave Symposium Digest*, pp. 1081-1084.
- [8] N. Dib and L. P. Katehi, "Characterization of Non-symmetric CPW Discontinuities," *1992 IEEE MTT-S International Microwave Symposium Digest*, pp. 99-102.
- [9] K. Koshiji, E. Shu and S. Miki, "An Analysis of Coplanar Waveguide with Finite Conductor Thickness - Computation and Measurement of Characteristic Impedance," *Electronics and Communications in Japan*, Vol. 64-B, No. 8, pp. 69-78, 1981.

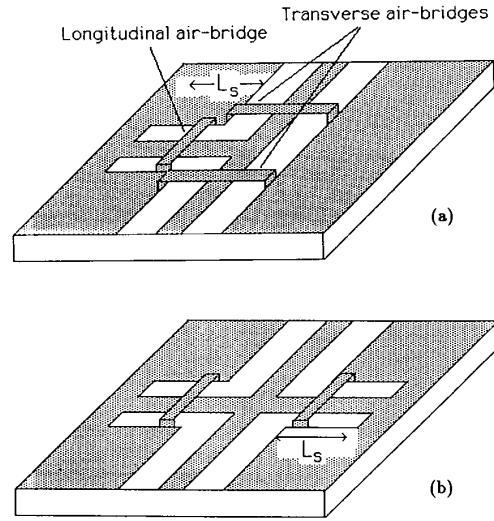


Figure 1: (a) The asymmetric short-end CPW shunt stub. (b) The symmetric short-end CPW shunt stub.

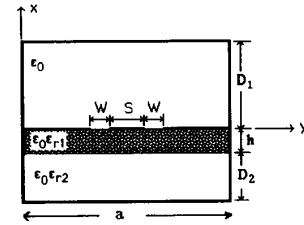


Figure 2: A suspended CPW structure inside a rectangular cavity.

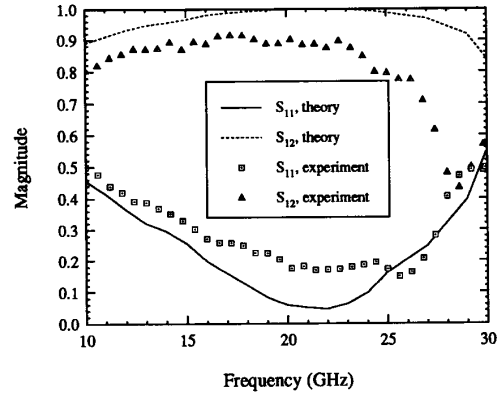


Figure 3: Scattering parameters of an asymmetric short-end shunt CPW stub without longitudinal bond-wire. ($L_s=1600 \mu m$)

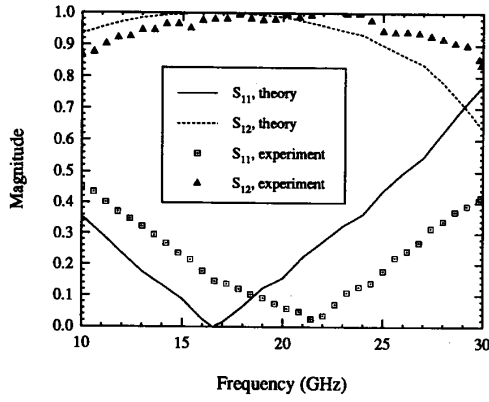


Figure 4: Scattering parameters of an asymmetric short-end shunt CPW stub with longitudinal bond-wire. ($L_s=1600\ \mu\text{m}$)

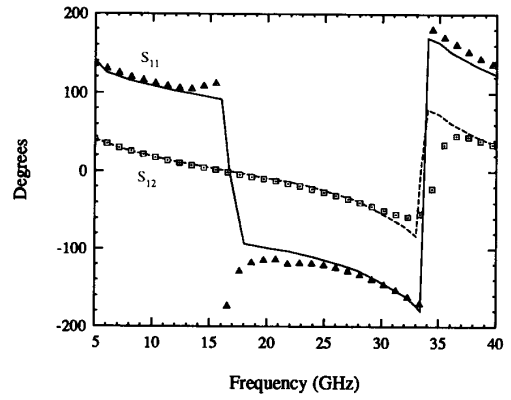
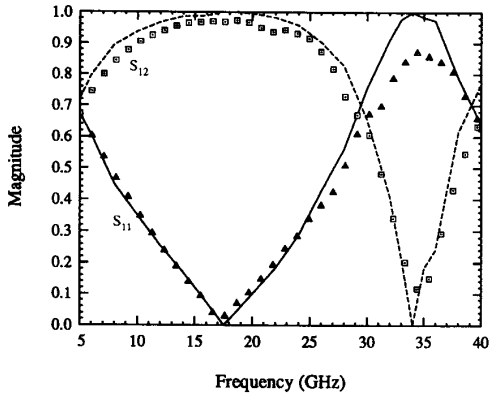
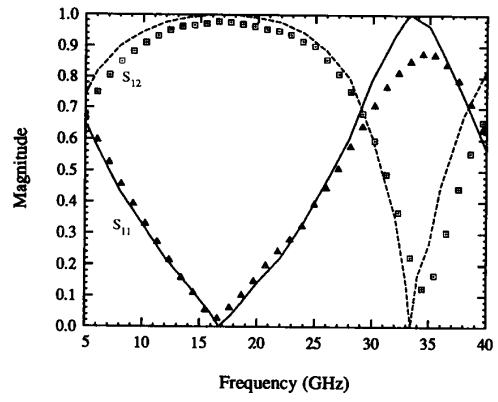


Figure 6: Scattering parameters of an asymmetric CPW shunt stub with longitudinal air-bridge. ($L_s=1650\ \mu\text{m}$)

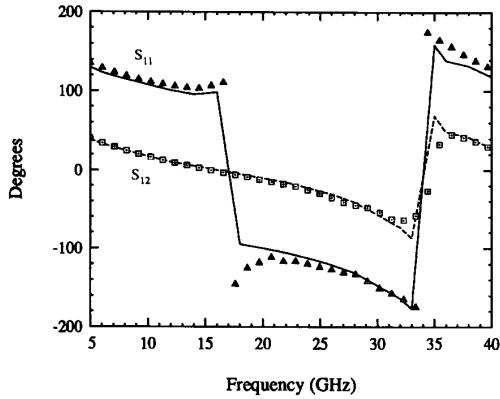


Figure 5: Scattering parameters of an asymmetric CPW shunt stub without longitudinal air-bridge. ($L_s=1650\ \mu\text{m}$)

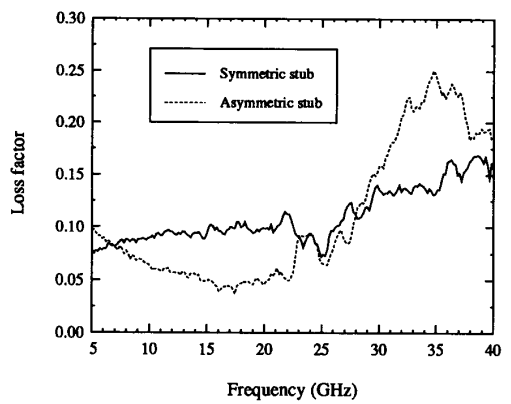


Figure 7: Measured loss factor for both the asymmetric and symmetric CPW shunt stubs with all air-bridges present. ($L_s=1650\ \mu\text{m}$)